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K/Ka-Band Channel Characterization for Mobile Satellite Systems

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ABSTRACT

NASA's Advanced Communications Technology Satellite provides an ideal spaced-based platform for the measurement of K- and Ka-band propagation characteristics for land mobile satellite applications. This paper reports and compares results from pilot tone tests at both K- and Ka-band in three environments: lightly shadowed suburban, moderately shadowed suburban, and heavily shadowed suburban. The results show that K- and Ka-band pilot tones experience significant multipath and fading effects with similar characteristics. Thus, both K- and Ka-band channels would require substantial coding or diversity techniques to realize reliable land mobile satellite communications in the suburban environment.

1. INTRODUCTION

Mobile satellite systems allow truly ubiquitous wireless communications to users anywhere and anytime. A mobile terminal is affected by shadowing and multipath interference caused by roadside obstacles and terrain conditions. The degree of shadowing depends on the length of the path which intersects the roadside obstacles. Many parameters effect the intersecting path including: elevation angle, nature and geometry of the obstacle (e.g., tree, utility pole), distance between the road and the obstacle, lane and direction of travel, and road surface conditions (e.g., rolling/flat, straight/curved). In addition, the antenna pattern, the environment, the season, and the carrier frequency also affect the degree of shadowing.

Propagation experiments at UHF (850 MHz) and L- (1.5 GHz) bands have quantified the shadowing and multipath interference effects [1, 2, 3] for these bands. NASA's Advanced Communications Technology Satellite (ACTS) provides a stationary platform ideally suited to the measurement of mobile propagation effects at K-(20 GHz) and Ka-(30 GHz) bands. Field tests conducted during the first 7 months of 1994 using JPL's ACTS Mobile Terminal (AMT) provide channel characterization data for these channels. Recently published results from AMT experiments [4, 5] and from the ACTS Mobile Propagation Campaign [6, 7] have provided insight into the K-band mobile satellite channel. This paper reports on the results of AMT experiments at Ka-band.

2. EXPERIMENTAL ASPECTS

1. *System Configuration*

The system configuration is illustrated in Figure 2. The basic features of the system include

- The fixed station or Link Evaluation Terminal (LET) located at the NASA Lewis Research Center in Cleveland, Ohio.
- ACTS, operating in the microwave switch matrix mode (MSM), i.e., as a bent pipe repeater, connects the fixed station with the mobile unit. The satellite was configured to provide two way communication between Pasadena, California (in the Southern California spot beam) and the LET (in the Cleveland spot beam).
- The AMT, a breadboard mobile terminal designed as a testbed for proof-of-concept designs using ACTS (see [8] for a detailed description).

The *forward channel* originated at the fixed station with a 29.634 GHz pilot tone. This pilot tone was received by ACTS, mixed to the downlink frequency of 19.914 GHz, and transmitted on the Southern California spot beam. The forward channel offered a composite C/N_0 of 55.63 dB-Hz and was the basis for the K-band results reported in [4, 5]. The *return channel* originated at the AMT with a 29.634

GHz pilot tone which was uplinked to ACTS, mixed to 19.194 GHz, and downlinked to the fixed station. The available C/N_0 on the return channel was 53.58 dB-Hz. The return channel formed the basis for the Ka-band results reported in this paper.

Typical Doppler shifts at this frequency (due to car motion) can be as high as 3kHz, with a rate up to 250 Hz/sec. In addition, uncertainties on the various oscillators along the link can accumulate about 2 kHz of frequency offset. The Doppler and frequency uncertainties can therefore be a large fraction of the data rates. In the AMT, the Doppler shift present on the pilot was tracked at the mobile terminal, translated in frequency, and used to pre-compensate (appropriately pre-shift) the data channel on the return link.

2. Antenna Tracking System

The AMT is equipped with a small, high gain reflector antenna which tracks the satellite signal in azimuth for a fixed elevation angle[1] [9]. The antenna is mechanically steered and acquires/tracks the satellite signal over the entire 360° of azimuth with a pointing error less than 0.2°. Vehicle turn rates of up to 45 degrees/second can be accommodated. The antenna provides an uplink EIRP of 22 dBW over a bandwidth of 300 MHz. The 3 dB beamwidth is ±9° in elevation and ±6° in azimuth. The reflector resides inside an ellipsoidal water-repelling radome with an exterior base diameter of 9 inches and a height of 3.5 inches.

The antenna pointing system enables the antenna to track the satellite for all practical vehicle maneuvers. The antenna is mated with a simple, yet robust, mechanical steering system. The antenna is smoothly dithered about boresite by one degree at a rate of 2 Hz. The pilot signal strength measured through this dithering process is used to compliment the inertial information derived from a simple turn rate sensor. This combination maintains the antenna pointing at the satellite even if the satellite is shadowed for up to ten seconds.

3. Data Acquisition System

Both the AMT and the fixed station were equipped with identical data acquisition systems (DAS). The DAS continuously recorded parameters important for link characterization. At the AMT, the DAS recorded forward channel parameters. The measurements included IF pilot tone level, noise calibration levels, mobile velocity (speed and direction), antenna pointing direction, mobile location, time, video images of the ACTS-AMT link, and an audio record documenting the test runs. At the fixed station, the DAS recorded return channel parameters such as the IF pilot tone level and noise calibration levels.

The IF pilot tone used to characterize the channel was filtered using a 17 kHz bandpass filter as shown in Figure 1. The filtered IF pilot tone was processed by a phase-locked loop and non-coherent power detector. The phase-locked loop generated in-phase and quadrature-phase voltage levels in a 1.5 kHz bandwidth. The non-coherent power detector generated voltage levels proportional to pilot power in a 100 Hz bandwidth. These signals were sampled at a rate of 4000 samples/second and were recorded on 5 Gbyte Exabyte tapes for off-line evaluation.

The time, vehicle velocity, and position were derived from an on board GPS system and updated at 10 Hz (time) and 100 Hz (velocity and position).

3. Test Runs

The configuration used for these experiments was slightly different from typical mobile propagation experiments. Normally, the transmitter is stationary while the receiver is mobile. In this case, the transmitter was mobile while the receiver was stationary. Data was collected solely from the return channel. The fact that the transmitter was mobile had no impact on the results of the experiment. All ACTS propagation results reported to date have been for the K-band link (19.914 GHz); in this case, the results are for Ka-band (29.634 GHz). As will be seen in later sections, results indicate that K- and Ka-band experience almost identical effects.

Data was collected in a variety of locations which may be broadly classified in three categories: lightly shadowed suburban, moderately shadowed suburban, and heavily shadowed suburban. These categories are somewhat subjective; however, the criteria used to label the road were as follows: 1) lightly shadowed roads had infrequent, partial blockage to the satellite, 2) moderately shadowed roads had occasional, complete blockage to the satellite, and 3) heavily shadowed roads had frequent, complete blockage to the satellite.

All tests were conducted in Southern California

[1] The elevation angle for experiments in the Pasadena area is 46°.

which does not experience large seasonal variations. Therefore, the propagation effects due to foliage do not change throughout the year.

1. Lightly Shadowed Suburban Environment

Orange Grove Boulevard in Pasadena, California, is a broad, level thoroughfare with trees lining both sides of the road. The trees lining this route are primarily Southern Magnolia with Fan Palm and Date Palm trees spaced 50 meters apart. The road is laid out in a north-south direction. With the satellite to the south-east, the western most lane (right-hand, south bound lane) presented the best look-angle to the satellite. In this lane, the AMT antenna boresite to the ACTS line-of-sight path just barely skirted the tops of the Palm trees on the east side of the road and, generally did not intersect the foliage of the Magnolia trees. This environment is characterized as lightly shadowed. A representative time series of the pilot power transmitted by the AMT and received at the fixed station is shown in Figure 3. The solid line represents the one second average of the 4000 samples. In addition, vertical dashed lines are displayed which connect the maximum and minimum values of the pilot power during the one second interval.

The statistics of the shadowing/fading are summarized by a histogram of the cumulative distribution of the pilot power received at the fixed station. The histogram of the run shown in Figure 3 is represented by the solid line in Figure 4. Also shown is the histogram of the cumulative distribution of the pilot power received by the AMT (at K-band) at the same time (this is the dashed line). The solid line models the 30 GHz land mobile channel where it is seen that the 1% fade level for Ka-band is 8 dB. In other words, 1% of the time the pilot signal is worse than 8 dB below the reference level. This is essentially equal to that at K-band.

2. Moderately Shadowed Suburban Environment

The center lanes of Orange Grove Boulevard represent a moderately shadowed suburban environment. Figure 5 shows the time series for a test run on the eastern center lane (left-hand, north bound lane). In this case, significant shadowing resulted from the intersection of the line-of-site path between AMT and ACTS by the Magnolia trees on the eastern side of the road. In addition, periodic blockage by the trunks of the Palm trees was observed. The statistics of the shadowing/fading are summarized by the histogram in Figure 6 where it is seen that the 1% fade level for Ka-band is 26 dB which is 1 dB better than the land mobile satellite channel at 20 GHz.

An interesting observation here is different lanes on the same road exhibit different fading levels. In this case, the difference in 1% fade levels is 18 dB which represents a remarkably wide variation due to lane diversity.

3. Heavy Shadowed Suburban Environment

To obtain results from a heavily shadowed suburban environment, a route along Grand Avenue in Pasadena, was selected. Grand Avenue is a narrow two lane road with many turns and runs in a generally north-south direction. The road is lined with a heavy mixture of Coastal Live Oak, Southern Magnolias, and Holly Oak. In many places along the route, the tree canopies completely covered the road blocking any direct line-of-site path between AMT and ACTS. This environment is creates severe shadowing/fading as illustrated in Figure 7. The statistics of the shadowing/fading are summarized by the histogram illustrated in Figure 8 where it is seen that the 1% fade level for Ka-band is well in excess of 30 dB (perhaps even as high as 45 dB). Results for the simultaneous return channel at K-band are also shown and are essentially equivalent.

4. Analysis

Each of the histograms illustrated in Figures 4, 6, and 8 displays the same characteristic shape. The slope between the reference level (0 dB) and 2 dB below the reference level is steep. This is characteristic of Ricean fading which occurs when reflected copies of the transmitted pulse accompany the line-of-sight signal. This steep curve is followed by a "knee" which forms the transition between the Ricean characteristic and the shadowed fading characteristic. Shadowed fading contributes a shallower characteristic to the curve which indicates that the combination of signal blockage (shadowing) and multipath interference (shadowed fading) is severe. The combination of these two characteristics suggests a "time share" between Ricean fading and shadowed fading as observed at L-band [1, 2] and K band [4, 6, 7].

A summary of the results for all runs conducted on 9 July 1994 is included in Table 1.

5. Conclusions

The results of the AMT Ka-band mobile propagation field tests show that the shadowing and fading processes are essentially identical for both K- and Ka-band frequencies and for the mobile transmitter and receiver. As such, the conclusions and results for K-band apply to Ka-band frequencies as well.

It may be possible to design link margins to provide reliable service for the lightly shadowed suburban environment at Ka-band. However, for areas with moderate and heavy shadowing, the link margin required to realize reliable communications with 99% availability is excessive (26 dB for moderate shadowing, and greater than 30 dB for heavy shadowing). An alternate approach would be to use shadowing/fading countermeasures (e.g., interleaved error control coding and antenna diversity). Such mitigation techniques, necessary for reliable Ka-band mobile communication within a suburban environment, are currently being considered within the NASA program.

6. Acknowledgments

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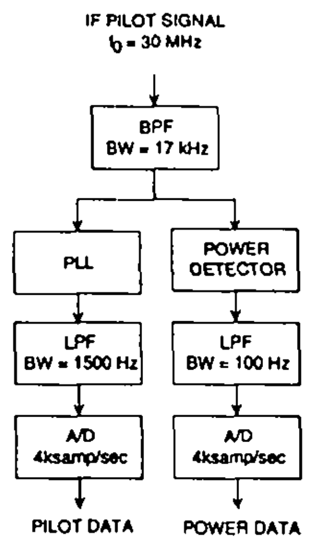

Fig. 1. Pilot Tone Signal Processing

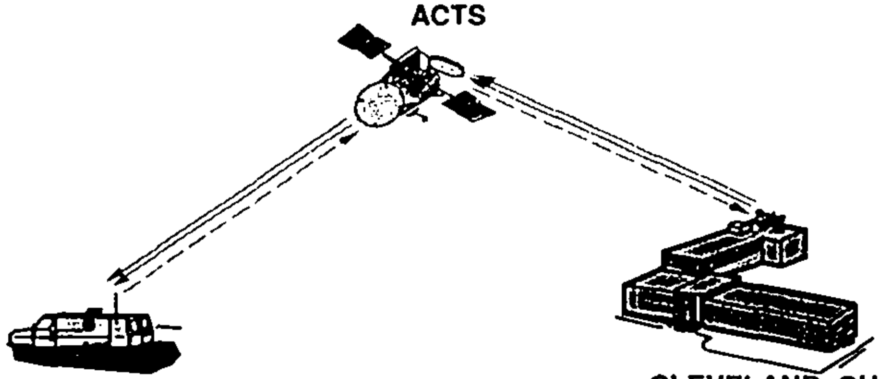

Fig. 2. System Configuration for AMT Propagation Experiments

Table 1. Summary of AMT Test Runs 9 July 1994 (Category 1 = lightly shadowed suburban environment, Category 2 = moderately shadowed suburban environment, Category 3 = heavily shadowed suburban environment).

		1% FADE LEVEL		3% FADE LEVEL		5% FADE LEVEL	
ROUTE	CATEGORY	K-band	Ka-band	K-band	Ka-band	K-band	Ka-band
Orange Grove Blvd. south bound	1	8 dB	9 dB	1 dB	1 dB	1 dB	1 dB
Grand Ave. north bound	3	>> 30 dB	>> 30 dB	>> 30 dB	>> 30 dB	>> 30 dB	>> 30 dB
Orange Grove Blvd. north bound	3	>> 30 dB	>> 30 dB	>> 30 dB	>> 30 dB	> 30 dB	> 30 dB
Grand Ave. south bound	3	> 30 dB	> 30 dB	26 dB	26 dB	19 dB	19 dB
Orange Grove Blvd. north bound	2	27 dB	26 dB	17.5 dB	17.5 dB	12.5 dB	12.5 dB
Arroyo Blvd. south bound	3	>> 30 dB	>> 30 dB	>> 30 dB	>> 30 dB	>> 30 dB	>> 30 dB
Arroyo Blvd. north bound	3	>> 30 dB	>> 30 dB	>> 30 dB	>> 30 dB	>> 30 dB	>> 30 dB

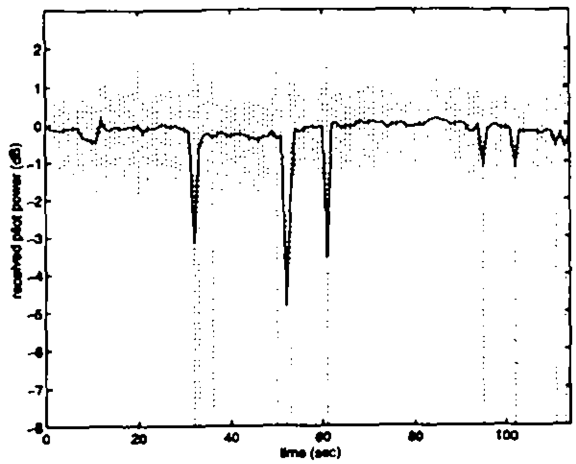

Fig. 3. Pilot Power (dB) vs. Time For A Lightly Shadowed Suburban Environment

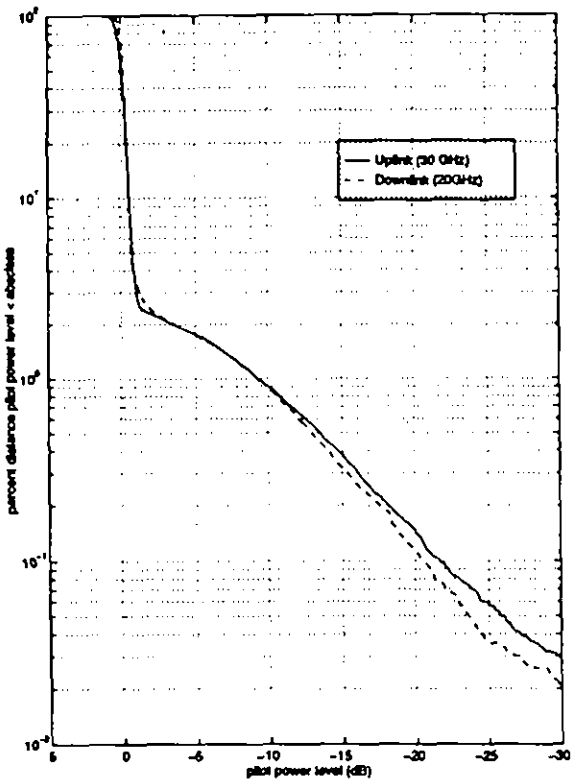

Fig. 4. Histogram of the Cumulative Distribution of the Pilot Power for a Lightly Shadowed Suburban Environment

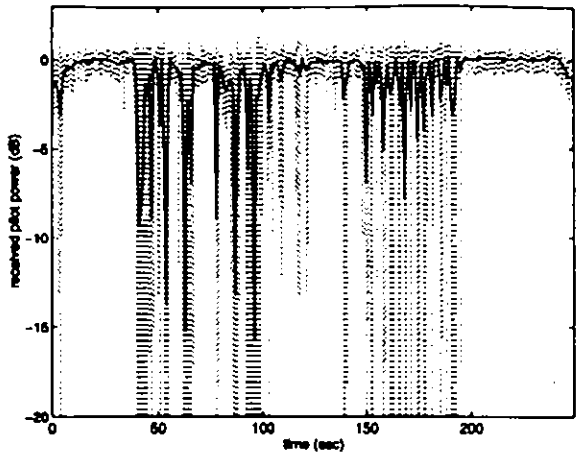

Fig. 5. Pilot Power (dB) vs. Time For A Moderately Shadowed Suburban Environment

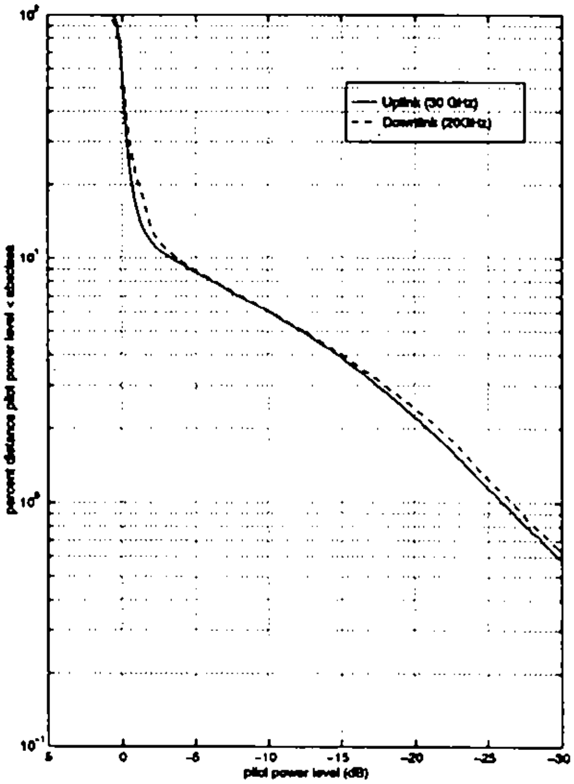

Fig. 6. Histogram of the Cumulative Distribution of the Pilot Power for a Moderately Shadowed Suburban Environment

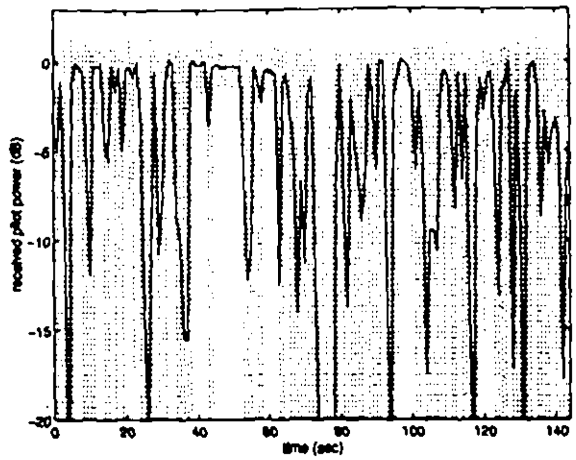

Fig. 7. Pilot Power (dB) vs. Time For A Heavily Shadowed Suburban Environment

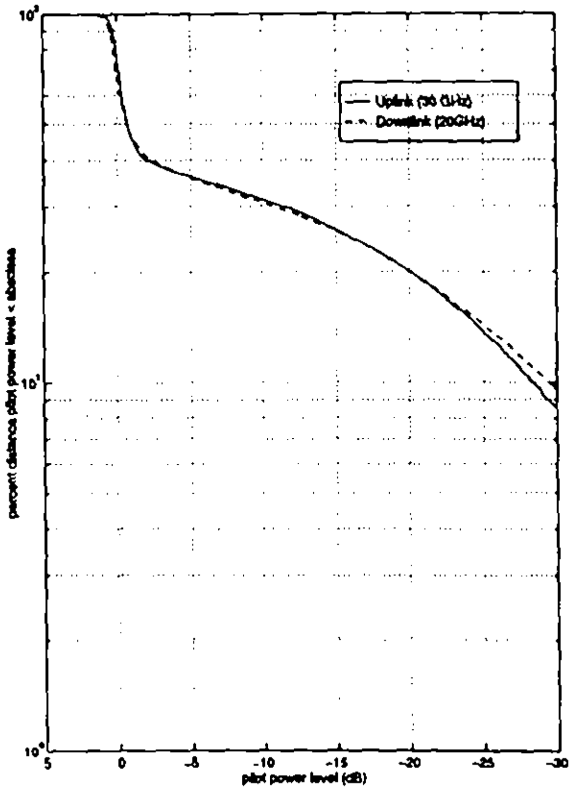

Fig. 8. Histogram of the Cumulative Distribution of the Pilot Power for a Heavily Shadowed Suburban Environment